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Auditory Effects of Noise on Air-Crew Personnel

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16. Abstract

Hearing-threshold tests were made on flight personnel of several sorts, including aerial-application pilots, flight instructors, private pilots, stewardesses, and FAA flight inspectors. Excluding those people whose flight experience is of short duration, each group shows some measurable degree of threshold shift, although this shift is frequently not enough to be regarded as a clinically significant entity. Data on the sorts of noise exposures each group commonly receives are presented, and some cautions are offered regarding interpretation of the data.

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I. Introduction.

The public has become generally aware that work around aircraft can be extremely noisy and perhaps even hazardous to hearing. Thus, no one is surprised that sound-attenuating earmuffs are worn by ground crews when they are assigned to ramps where engines are running. People who live under flight paths often complain about the external sounds created by airplanes. But comparatively few people have expressed concern for the noise *inside* the aircraft and for the people who are exposed to it (however, there are exceptions, such as Gasaway, 1970; Stone, 1969; Tobias, 1968 a,b,c; and Wick *et al.*, 1963). Studies of cabin and cockpit noise show that many planes are potential producers of permanent threshold shifts (Figure 1) for people who are regularly exposed to the sound levels in the cockpit or the cabin (Tobias, 1968 a,b). Helicopters and planes with open cockpits are the noisiest. Then, more or less in order, are light single-engine airplanes, light twin-engine planes, piston-driven planes in air-transport use, turboprop planes, planes with wing-mounted jet engines, and planes with rear-mounted jet engines. Of course, the rear-mounted jet-engine aircraft can be quite noisy toward the rear of the cabin, but toward the cockpit, they are generally quiet. Since the concern of this paper is with the hearing of members of flight crews, the effects of noise at the rear of the cabin can be generally ignored for everyone except the stewardess, who rides there during takeoff and landing, and, as the data will show, her problem with noise is relatively minor.

The amount of hearing problem likely to be engendered by a given amount of noise is a function of the susceptibility of the listener, and of the amount of time he is exposed. A comprehensive investigation would probably show that the most exposed people are aerial-application (crop-duster) pilots, flight instructors, helicopter pilots, business and other commercial pilots, stewardesses, airline pilots and flight engineers, and Federal Aviation Administration flight inspectors. What happens to the hearing of such people? Systematic attempts to answer that question are few. This study was devised to provide part of the data from which an answer can be derived.

First, let us look at the amount of noise the various groups receive. The most time in the air probably accrues to aerial-application pilots and to flight instructors; they commonly fly for 10 hours or so every day that weather permits, and, in many parts of the country, that number is increased to 14 hours a day or more. They work as many days of the year as possible, and normally they use aircraft whose noise levels are among the highest. Many aviators involved in agricultural work still use open-cockpit airplanes in which the wind-blast noise is clearly excessive for any duration of exposure (Tobias, 1968c). Helicopter pilots, too, work in extremely high intensities of noise, but the duration is considerably shorter than it is for ag pilots. For both of these groups, some sort of hearing protection—a helmet, or headset cushions, for example—is normally used. Although not entirely satisfactory, these devices do afford some attenuation. In a helicopter, the amount of protection can often be presumed to be somewhat better than in an aerial-applications plane. However, it was not possible to locate an adequate number of non-military helicopter pilots to test (analyzing the hearing losses of military pilots is complicated by their exposure to gunfire), and so that group is not included here.

Airline pilots were also excluded because these people are required to have semi-annual physical examinations, including hearing tests, and only a tiny minority fail because of hearing problems. Although the precision of our laboratory tests might have turned up some degree of noise-attributable threshold shift, special tests of these men would likely not be particularly informa-

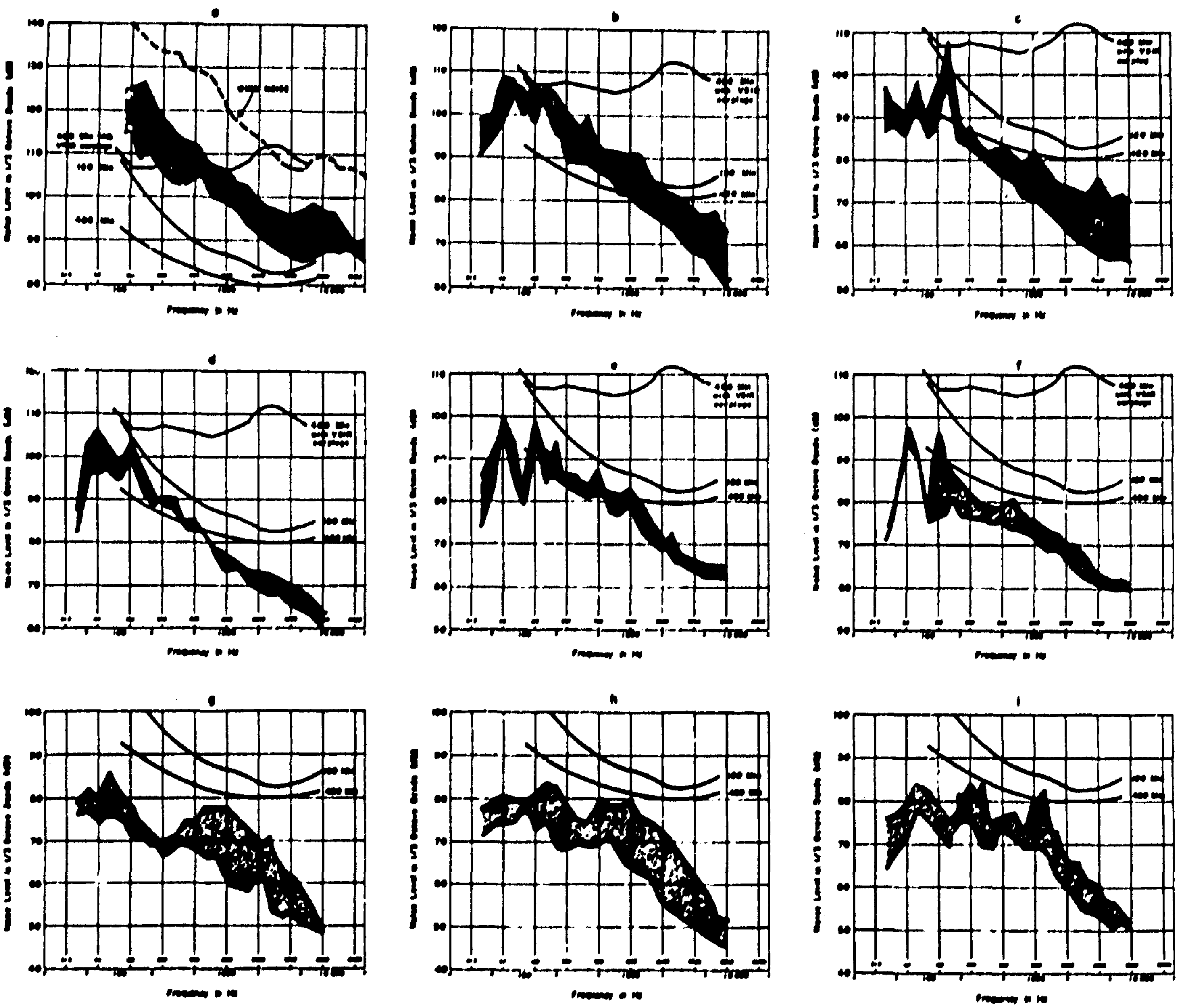

FIGURE 1. Noise spectra in the cockpits of several types of aircraft. (a) An open-cockpit aerial-application plane with a small windscreen, (b) a light, single-engine plane, (c) a light, twin-engine plane, (d) a twin-engine plane of a type formerly used in air transport, (e) a two-engine turbo-prop in air-transport use, (f) a four-engine turboprop in air-transport use, (g) an air-transport jet with wing-mounted engines, (h) an air-transport jet with rear-mounted engines, (i) a business jet with rear-mounted engines. Superimposed on each spectrum are three damage-risk criterion (DRC) curves (Kryter *et al.*, 1966): the lowest curve represents the maximum acceptable sound level at any frequency (a spectral line that rises above a DRC curve at any point represents a noise that can be considered hazardous) for noise exposures of eight or more hours per day; the next DRC curve represents the maximum acceptable level for exposures of two or more hours per day; the top DRC curve shows the maximum acceptable exposure for eight-hour-per-day exposures for a listener wearing properly fitting earplugs. Spectra (g), (h), and (i) lack this last DRC curve.

tive; for the most part, they fly in the quietest planes, and they do so for relatively few hours per week. The same statements apply to flight engineers.

Some commercial pilots, notably those who fly "company planes" for industry, probably have somewhat longer periods of exposure than airline pilots, and they may fly somewhat noisier aircraft. Such aviators, though, are not representative of the majority of commercial pilots. Most of them handle charter flights as they come along, but make the largest part of their salaries

(and receive the largest part of their noise exposures) as flight instructors, and so they properly are classed as instructors.

It was impractical to test one group of people who are regularly exposed to the noises inside airplanes; there is no sensible way to select representative traveling salesmen and professional travelers. The group was excluded from this series of studies. Still, although the amount of exposure-per-week may be fairly high for travelers, they generally try to "get off the road" when they have the chance, and their long-term noise exposure is probably fairly small.

Like salesmen, stewardesses have frequent exposures to noise while they fly, but until very recently, most had only a few years of flight experience. On the average, these girls have kept flying for only two or three years. However, even before the regulations changed, some continued to fly for 15 or 20 years, and today there is a good chance that longer periods of exposure will become common. Thus, the stewardess data will be much more important in the future.

FAA flight inspectors form a special group. Their log books show only a little recent flight time—certainly not much more than most private pilots have. Yet these are, without exception, people with a great deal of past flying experience, and many of them still spend a large part of their time in the air. These hours are not usually logged, though, because the time is spent in testing prospective licensees, and in traveling to accidents, to inspection sites, or to testing sites; additional flight time is spent in making route checks on air-taxi services, in witnessing or performing flight checks and type-rating tests, and in observing various other aircraft operations. Only occasionally does the inspector serve as pilot-in-command. Thus, despite the appearance of little flight time, inspectors are among the fliers who are most exposed to noise.

For these series of tests, then, audiometric examinations were performed on aerial-application pilots, flight instructors (including commercial pilots), stewardesses, and FAA flight inspectors. Additionally, a group of older-than-average people with private-pilot licenses was tested.

II. Method.

Experimental subjects were selected from those available to this laboratory. They included 12 aerial-application pilots, ranging in age from 22 to 58 years (mean 39.3), 15 flight instructors ranging from 23 to 53 years (mean 34.9), 12 FAA flight inspectors ranging from 36 to 56 years (mean 44.0), and 16 private pilots ranging from 40 to 58 years of age (mean 48.9). (The mean age for all private pilots is 35.8 years.) Two groups of stewardesses were tested: one group of 10 girls ranging in age from 26 to 39 years (mean 29.4), with experience ranging between 6 and 15 years, was tested in the same way that the pilots were; another group of 106 stewardesses ranging in age from 21 to 44 years (mean 26.7) was tested by a somewhat different method. Additional subjects included control groups (matched for age) for all pilots and for the 10-stewardess group. For the group of 106 stewardesses, each girl served as her own control.

Data collection for each subject started with a short history including age, exposure to aircraft noise in hours-per-week, total years of flying experience, and, where it was pertinent (as, for example, with FAA inspectors), total number of hours in the air. Questions were also asked about other kinds of noise exposure, such as gunfire, rock music, snowmobile and motorcycle riding, and so on. Information was also requested about known past history of ear disease.

Each subject was tested on a Békésy audiometer (Grason-Stadler model E-800 or model 1701). This device automatically produces a continuous-frequency audiogram.

Audiograms were inspected for indications of noise-induced hearing loss or threshold shift. This inspection was based on an objective criterion. High-frequency threshold shifts are not necessarily evidence of noise damage, but a dip in the threshold curve (the dip or tonal gap appears as a depressed threshold in a restricted frequency region) somewhere between 2000 and 6000 Hz is generally accepted as indicating acoustic trauma. A simple measurement of threshold at 4000 Hz is not an adequate test. To make a meaningful test, first a smoothed threshold curve is produced by joining the center points of each excursion of the audiometer's marking pen (Figure 2). Then, in the event that an apparent dip in acuity is noted anywhere between 2000 and

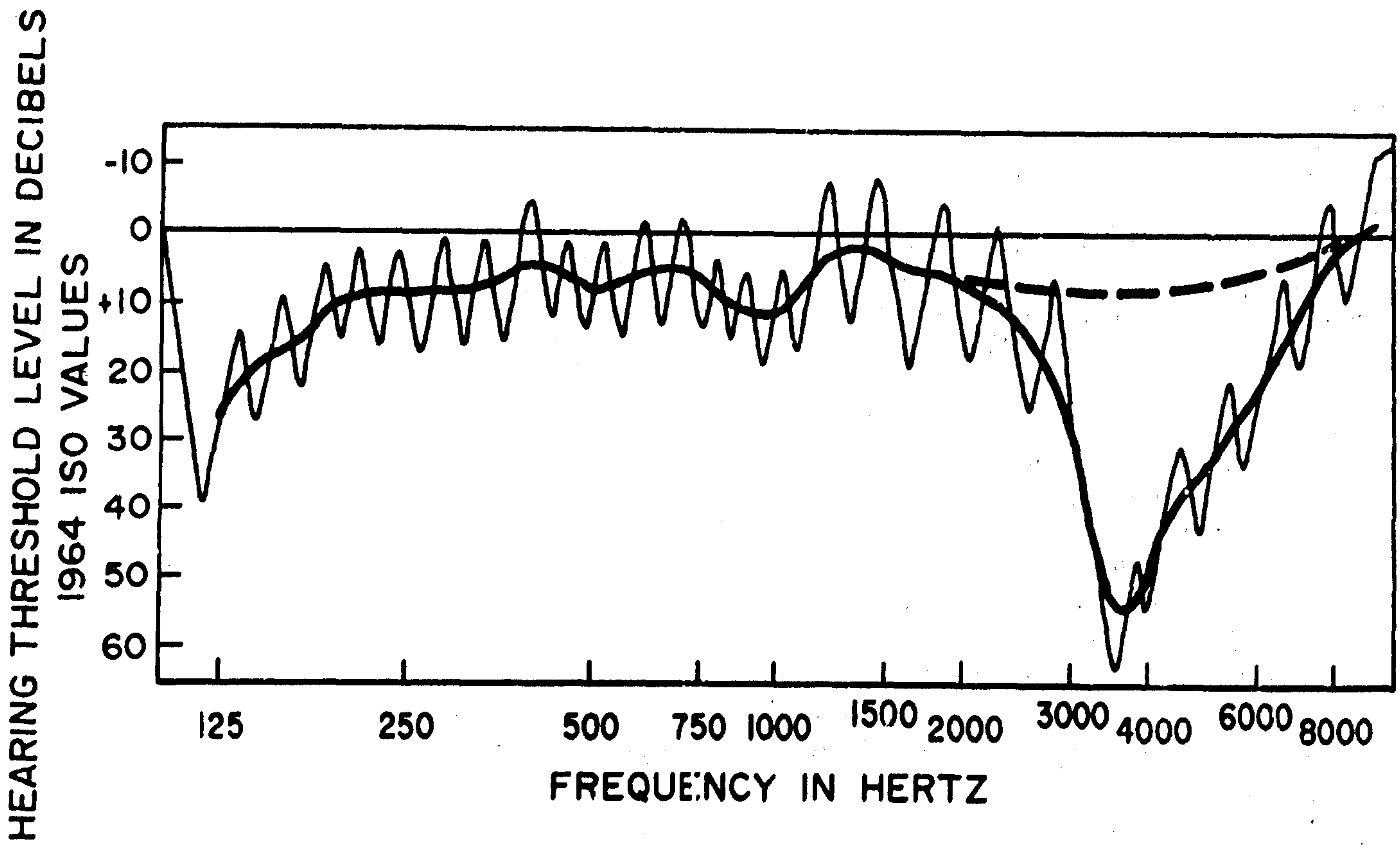

FIGURE 2. Threshold-dip graph. The lighter, oscillating curve is the one plotted by the Békésy audiometer. The heavier, solid line is the smoothed threshold curve. The dashed line represents the interpolated "continuation line" described in the text. In this example, the depth of the high-frequency dip is about 45 dB, a relatively large value for subjects used in the present study.

6000 Hz, the curve is smoothed as if the dip were not there. That is, a smooth continuation line is inserted, in the gap, to join the threshold curve at frequencies below the dip to the threshold curve at frequencies above the dip. The depth of the dip is then taken as the maximum vertical distance between the inserted line and the threshold line. Separations deeper than 15 dB were classified as significant. Any time a dip was more than 15 dB for a subject, he was tallied as having a threshold shift that might be attributable to noise. It was necessary to use this kind of criterion because of the huge variations in frequency at which tonal gaps appear. An average of all the audiograms in a group would wash out most of the information. Measuring the hearing loss or threshold shift only at 4000 Hz might or might not reflect the true state of the subject's hearing, particularly in the relatively unexposed groups such as stewardesses. Also, the statistical treatment was made relatively easy by this dichotomizing procedure.

Comparisons between experimental and control groups were made using Fisher's Exact-Probabilities Test. For these tests, the differences between experimental and control groups are large enough so that no more than 10 subjects per group were required. In some circumstances, more were tested—when extra subjects were available, they were used.

Controls for the group of 106 stewardesses were the less-exposed members. The 106 were separated into several series of two groups; in each series, the people with less flight time were compared to those who had more experience. Both the proportion with dips in each group and the size of the average threshold shift were studied. The groups were divided at several ex-

perience levels to try to find whether a measurable change arises at some particular point. Divisions were made at 1000-hours experience (approximately one year of work), 2000 hours, 3000, 4000, 5000, 6000, 7000, 8000, 9000, and 10000 hours. In each case, comparisons were made between those with more than the criterion-number of hours, and those with the criterion-number or less.

III. Results.

A. *FAA Flight Inspectors.* Every Federal Aviation Administration flight inspector tested shows some degree of threshold shift attributable to noise exposure. On the average, the loss of high-frequency hearing would be classed as moderate (the worst thresholds are in the range from 40–60 dB HTL, ISO). Statistically, the fact that the entire test sample evidences audiometric dips is significant. However, flight inspection is not likely the major source of these threshold shifts. Rather, it is the previous flight experience, primarily in commercial or military aviation, that has decreased the hearing acuity. Each one of the subjects had many thousands of hours of flight time logged before he was tested. Thus, so far as their histories of noise exposure are concerned, they are really displaced commercial and instructor pilots.

B. *Flight Instructors and Commercial Pilots.* Those who fly light planes for a living, either as charter pilots or as instructors (or as both) show measurable high-frequency threshold shifts ranging from mild to moderate (the worst thresholds are in the range from 25–60 dB HTL, ISO) in about 85 per cent of the cases (13 out of 15). Statistically, these shifts are significantly more frequent than those found in the control group ($p<.005$).

C. *Agriculture Pilots.* Aerial-application pipilots, among all the people who make their living inside airplanes, receive the longest exposures to the most noise. Every pilot in this group had some loss of hearing, with worst thresholds ranging from 30–70 dB HTL, ISO. When compared to the control group's hearing loss, this 100 per cent value turns out to be highly significant ($p<.001$). Clearly, agricultural aviation is not good for hearing. Many of these pilots wear helmets or headsets, but, particularly for the person who flies in an open-cockpit plane, such circumaural protection does not keep out enough of the predominating low-frequency components of the noise. In fact, it is even unlikely that a combination of a good circumaural earmuff and a good insert earplug would provide adequate protection against the wind-blast that a pilot gets whenever he puts his head over the side.

D. *Air Transport Pilots.* This laboratory has not made a systematic collection of audiometric tests on airline pilots and flight engineers, so no body of data on this population can be included in this study. Still, it is worth noting that, of the few who have been seen and tested, all have had threshold shifts large enough to be included in the noise-affected group, according to the criterion used here. However, among 70 or 80 thousand medical examinations involved, only one or two air-transport people a year are grounded because of their hearing. That means that their threshold shifts, although they sometimes meet the laboratory criterion, are not adequate to interfere with speech reception in the noisy flight environment.

E. *Stewardesses; Group I.* Of the 10 stewardesses in the first group (all selected to have six years or more of flight experience), eight were shown to have noise-attributable threshold changes. Among the girls in the control group, only two showed a loss similar to that seen in the stewardesses. Of these, one had spent a considerable period of time in target shooting. The difference between groups is significant ($p<.001$), which suggests that the noise exposure of flight does produce a measurable degree of threshold shift in those who have spent more than a few years flying. However, despite the fact that this shift occurs, no case of noise-induced shift in either group of stewardesses could be considered clinically important. The very largest dip measured is a narrow tonal gap (no worse than 30 dB HTL for any stewardess tested, and averaging only 12 dB HTL) of the sort that has little or no effect on the hearing of speech. It must be considered extremely unlikely that any of the stewardesses is consciously aware of any debilitating problem with her hearing.

F. *Stewardesses; Group II.* The 106 stewardesses in the larger group were tested in order to try to answer some other kinds of questions. The attempt was only partially successful. For

example, it turned out not to be possible to specify the effects of noise from various types of aircraft. For one thing, short-term stewardesses (who might have flown only one type) show relatively little threshold shift, making comparisons useless; longer-term girls invariably have flown several types. The interactions and confounding factors are too great to permit the desired measurements to be made.

However, it was possible to plot the way in which patterns of threshold shift change with added years of flying experience. For the first few years, according to this sample, the worst threshold for each girl averages about 10 dB (ISO).* (This value is not necessarily part of a dipping region.) Then, after about seven years of experience, the worst-threshold average jumps to something more than 20 dB (Table 1). In no case is the aircraft-noise-induced threshold shift large enough to be noticed except on a test as sensitive as this one, but the change is indicative of the level of the sound fields in which these people work. There is, of course, no certainty that the shifts measured are a result of the time spent in the flight environment. It might be possible to interpret this change as showing that the planes that were used several years ago were much noisier than those that are around today. But more likely, these shifts are the result of relatively long-term cumulative exposures, without regard for the types of aircraft involved.

TABLE 1. Worst-Threshold Averages for 106 Stewardesses

Hours of flight experience	*N*	*Worst-threshold average*
1-1000	15	10
1001-2000	11	12
2001-3000	18	10
3001-4000	15	7
4001-5000	9	14
5001-6000	10	14
6001-7000	6	9
7001-8000	5	18
8001-9000	2	32
9001-10000	4	19
10001+	11	21

An additional attempt was made to clarify the critical period for noise exposures in stewardesses. In this instance, short-term girls were used as controls for long-term girls. This approach is imperfect in two or three regards, but it does permit a classification of sorts. Chi-square contingency tables were built for various cutoff durations of experience: those with 1000 hours or less of flight time were compared with those with more than 1000 hours; another comparison was made at a cutoff of 2000 hours, and still others were run for 3000, 4000, 5000, 6000, 7000, 8000, 9000, and 10000 hours (Table 2). The result is that, when stewardesses with fewer than 6000 hours are included in the "more-experienced" sample, there is no useful significant difference between the more-experienced and the less-experienced groups. But once the cutoff reaches 7000 hours, the groups are consistently different ($p<.05$). The finding suggests that it takes the first seven years or so for the noise effects to reach our criterion values. Again, it must be

TABLE 2. Influence of Flight Experience on Dips in Hearing Thresholds for 106 Stewardesses

Hours of flight experience	*Number with dips ≥15 dB*	*Number without dips ≥15 dB*	*Chi-square (listed only where significant: $p<.05$)*
1000 or less	10	5	
More than 1000	53	38	
2000 or less	19	7	
More than 2000	47	33	
3000 or less	27	17	
More than 3000	38	24	
4000 or less	33	26	
More than 4000	30	17	
5000 or less	38	30	
More than 5000	26	12	
6000 or less	42	36	
More than 6000	19	9	
7000 or less	44	40	5.07
More than 7000	18	4	
8000 or less	46	43	6.38
More than 8000	15	2	
9000 or less	47	44	5.08
More than 9000	18	2	
10000 or less	50	45	4.425
More than 10000	10	1	

*One stewardess with less than two years of experience had a moderate low-frequency loss of hearing. The decrement was clearly not related to noise exposure. She had no history of infections or blockages, and was referred to an audiological service in her home town. She was found to be otosclerotic. Her data are not included in the "worst-threshold" average. Another stewardess with a 9-year history of working in the pits at hydroplane races was also excluded from this average.

remembered that these girls still have not suffered a hearing loss of any sort that could be considered a health or a social hazard.

G. *Older Private Pilots.* Tests were run on a number of people over 40 years of age with private-pilot licenses to try to determine whether the occasional recreational flying done by the amateur is as likely to produce hearing damage as the more concentrated time spent by the professional. Although more than 75 per cent of these private pilots showed some threshold shift, that proportion was not significantly different from the proportion seen in control subjects who have not flown (but have otherwise lived in acoustically similar environments). The conclusion to be drawn is not necessarily that piloting a light aircraft for pleasure and personal transportation does not have an effect on hearing (although that *might* be true); from these data, it is only proper to infer that the noise exposures received by pilots are not discriminably different in their effects from the noise exposures received by non-pilots. With all other groups tested, statistical comparisons of the *depth* of the dip, measured in decibels (for those subjects for whom a dip met the 15-dB criterion), showed the experimental groups all to be affected to a significantly higher degree than the control groups. In the case of these private pilots, though, no such significance exists, and that fact might mean that no *difference* exists.

IV. Conclusion.

Among the people who fly most, shifts in hearing threshold are common. In some cases, these shifts seem not to be different from those experienced by non-flying control groups, but often, the aircraft-noise exposure makes a difference. The use of hearing protection will help to solve the problem for most groups where the threshold shift is large. For others, though, no real difficulty with hearing occurs. Most stewardesses, for example, would be safe enough if they simply used their earplugs while seated between the engines in rear-engine jets. However, the use of protective devices cannot hurt any flying personnel, and could certainly help those with the greatest exposures to cockpit and cabin noise.

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